CALIFORNIA DIVISION OF MINES AND GEOLOGY

FAULT EVALUATION REPORT FER-150

Wheeler Ridge and Pleito Fault Systems

Southwestern Kern County

by

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INTRODUCTION

The Wheeler Ridge and Pleito fault systems*, located in rural southwestern Kern County (Figure 1), are each composed of a series of folds and south-dipping thrust faults. Chief among these faults and folds are the Pleito thrust (the leading thrust in the Pleito thrust system), the Wheeler Ridge thrust (the leading thrust in the Wheeler Ridge thrust system), and the Los Lobos fold.

The Wheeler Ridge and Pleito fault systems are being evaluated as part of a state-wide effort to evaluate faults for recency of movement. Those faults determined to be sufficiently active and well defined are zoned by the State Geologist as directed by the Alquist-Priolo Special Studies Zones Act of 1972 (see Hart, 1980). Although some persons may also include the structurally related White Wolf fault as part of the Wheeler Ridge thrust system, the White Wolf fault is not evaluated as part of this FER.

The faults evaluated in this FER lie in the Grapevine, Mettler, Pleito Hills, Coal Oil Canyon, Eagle Rest Peak, Connor SW, Santiago Creek, and Pentland 7.5-minute quadrangles. Special Studies Zones maps have been issued for five of these quadrangles (Eagle Rest Peak, Santiago Creek, Grapevine, Mettler, and Coal Oil Canyon; California Division of Mines and Geology, 1974a; 1974b; 1976a; 1976b; 1976c); however, faults that are a part of the Wheeler Ridge and Pleito fault systems have been zoned only in the latter three quadrangles.

*Convention dictates that thrust fault systems be named after the leading thrust (Boyer and Elliott, 1982). However, Davis (1983) has referred to these faults as part of the Pleito thrust system, presumably because the Pleito fault is better defined at the surface than is the Wheeler Ridge fault (even though the latter is the leading thrust). Since subsurface data demonstrating that the two faults connect at depth are lacking, and for the sake of clarity, these two faults are herein referred to as two separate, but related, systems.

Since the recommendations (see below) call for zoning faults which would require revising the existing SSZ map of the Eagle Rest Peak quadrangle, this FER also briefly addresses that segment of the San Andreas fault within that quadrangle.

REGIONAL GEOLOGIC SETTING

The Wheeler Ridge and Pleito Fault Systems

The Wheeler Ridge and Pleito fault systems are part of a complex of south-dipping thrust faults and associated folds that result from compression in the area adjacent to the San Andreas fault (Davis, 1983). Davis (1983) estimated that the Wheeler Ridge and Pleito fault systems have accounted for a total dip separation of 7 km (4 1/3 miles) over about the last 5.0 million years.

That the Wheeler Ridge and Pleito fault systems might be active is suggested by their proximity and relationship to two historically active faults, the San Andreas and the White Wolf. The San Andreas fault, located about 11 km (7 miles) south of the Pleito fault, is a right-lateral, generally northwesterly striking fault along which more than 500 km (300 miles) of displacement has apparently occurred. Immediately south of the area studied in this FER, however, the San Andreas strikes more westerly. This change of strike of the fault in this region has resulted in a significant amount of compression, which, in turn, has resulted in the formation of several thrust faults and folds on both sides of the San Andreas. Almost all of the thrust faults flanking the San Andreas fault dip towards the San Andreas; in other words, the San Andreas lies hindward of these thrusts.

The Wheeler Ridge, Pleito, and White Wolf faults are similar. All three are south-dipping thrust faults that rim the southern San Joaquin Valley. The White Wolf fault appears to be a relatively simple thrust (consisting of only a few fault strands) along the northern flank of the Tehachapi Mountains. Surface rupture occurred along this fault in 1952 (see Buwalda and St. Amand, 1955). West of the main 1952 rupture zone, the White Wolf fault is only known as a subsurface feature which trends southwestward towards Wheeler Ridge. Subsurface data suggests that the fault steepens to a steeply dipping reverse (Dibblee, 1961) or near vertical fault (Davis, 1983) near Wheeler Ridge.

Historic surface rupture has not occurred along the south-dipping Pleito fault. However, a distinct scarp across Holocene deposits is evident along the north flank of the San Emigdio Mountains (Dibblee, 1973b; Hall and others, 1981). As will be explained later in this FER, the south-dipping Wheeler Ridge thrust also once was locally evident as a well-defined scarp across several alluvial fans along the north flank of Wheeler Ridge (see section on aerial photo interpretation). Buwalda and St. Amand (1955) documented several surface ruptures along normal faults on Wheeler Ridge in 1952. Presumably these normal faults are secondary faults in the block overlying a primary thrust fault (probably the Wheeler Ridge thrust).

It appears that the Wheeler Ridge and Pleito fault systems each are part of imbricate fans of thrust faults, based on the limited subsurface data readily available. The leading (lower) thrust faults in these fans appear to be the Wheeler Ridge and Pleito faults, respectively. The relationship between the Wheeler Ridge fault and the White Wolf fault is poorly understood. Davis (1983) has suggested that the Wheeler Ridge fault may override the White Wolf fault. Since these two faults may be distal ends of leading thrusts in the same system, the name Wheeler Ridge-White Wolf thrust system may be appropriate. However, this name has not been used to avoid the implication that all of the White Wolf fault is addressed in this FER.

The San Andreas fault is a major right-lateral strike slip system which separates the Pacific Plate from the North American Plate. Historical records indicate that the great California earthquake of 1857 was accompanied by several meters of lateral slip along this segment of the San Andreas (Sieh, 1977). Sieh estimates that the long term rate of slip in the northern Carrizo Plain (northwest of the area studied) is about 37mm/year or more. Near Palmdale (southeast of the area studied), Sieh estimated that nine fault rupture events, each having about 3 to 5 meters of displacement, occurred between the sixth and ninth centuries A.D. Further discussion of the displacement history of the San Andreas is beyond the scope of this FER. Suffice to say, repeated fault rupture has occurred along the segment during Holocene time.

SUMMARY OF AVAILABLE DATA

Pleito thrust fault

The earliest, reasonably detailed geologic maps of the study area are those of Hoots (1925; 1930; see Figures 2A, 2C, 2D, 2E, and 2H). Hoots documented the existence of several generally east-west trending, south-dipping faults, the single most prominent of which, the Pleito fault, he determined has a maximum stratigraphic offset of at least 3,000 meters (10,000 feet). Hoots (1930) reported that the dip of the Pleito fault varied between 10° and 45°. Although Hoots acknowledged that landsliding may have complicated the geology of the area, he dismissed as unlikely the possibility that the low angle-fault segments were really landslide slip planes. His geologic maps show no landslide deposits on the hanging block.

Both of Hoots' (1925; 1930) maps show the Pleito fault as extending from Santiago Creek to Grapevine Creek (note that he did not map the fault near the obvious scarp at Grapevine, but projected the fault out under the valley in a more northerly location). However, in his thesis, Hoots refers to the segment west of Telegraph Creek as the Pleito fault, and to the segment east of Section 32, T. 11 N., R. 20 W. (Figure 2C), as the Wheeler Ridge fault. Subsequently, some petroleum geologists have referred to this thrust as the Wheeler Ridge fault (see Callaway and Rheem, 1961, for example), although most call it the Pleito fault . Hoots (1930) did not use the name "Wheeler Ridge fault" either in his text or on his map, implying that by 1930 he had concluded that these two fault segments were actually the same fault.

Hoots' 1930 map shows the Pleito fault as bounding Quaternary landslide and terrace deposits. However, the same map also locally shows the fault as concealed by Quaternary terrace deposits and Holocene alluvium. In both papers, Hoots (1925; 1930) states that movement undoubtedly occurred along the Pleito fault during Pleistocene, possibly late Pleistocene, time.

The next detailed map showing the Pleito fault apparently was that of Dibblee and Kelly (1948). They depicted the Pleito fault as concealed by Quaternary terrace gravels. Their map lacked any legend, but this investigator infers that these deposits are Pleistocene in age based on Dibblee (1973a).

In 1961, a generalized geologic map of the area appeared in an AAPG guidebook (Dibblee, 1961). This map lacked any symbol for concealed faults. As a result, Jennings and Strand (1969) depicted the Pleito fault as cutting Quaternary terrace deposits near San Emigdio Creek (Figure 2E). They also depicted the Oak Hill fault of Wood and Dale (1964) as cutting Quaternary terrace deposits (Figure 2E) even though Wood and Dale depict both the Pleito and the Oak Hill as concealed by Quaternary deposits. Dibblee (1961) did not show the Oak Hill fault.

Dibblee (1973b) recognized that the Pleito fault was most probably Holocene based on the existence of a scarp across the alluvial fans of Tecuya and Grapevine Creeks (Figure 2A). On the same map, Dibblee also depicted the fault as concealed by Pleistocene alluvium northwest of Salt Creek. Still farther northwest, Dibblee (1973c) shows the fault as cutting Quaternary landslide deposits and bounding Holocene alluvium (Figures 2D and 2C). Near San Emigdio Creek, he shows virtually all of the faults mapped as concealed by Pleistocene alluvium, although locally one trace of the Pleito fault is depicted as cutting Pleistocene fanglomerate (Dibblee, 1973e; see Figure 2E). The lack of evidence for Pleistocene offset appears confirmed by Davis (1983) who indicates that the western segment of the Pleito fault does not cut the youngest and lowermost (probably late Pleistocene) erosional and depositional surface present.

Park (1974) compiled a set of maps depicting faults and a simplified version of the areal geology for use in the Kern County Seismic Safety Element (Figures 2A through 2E). Many of the faults depicted by Park are based on subsurface data. The geologic units have been so generalized that it is not possible to determine precisely what units are or are not offset by any given fault and, more importantly for the purposes of this evaluation, it is not possible to determine the precise ages of these units. Note that Park's location of the Pleito fault near Grapevine differs somewhat from that shown by Dibblee (1973b) even though Dibblee's map is the only reference cited by Park which shows the fault in this area. This discrepancy suggests that Park used additional (uncited) information, did not carefully reproduce the work of others, or both. That the former is locally the case is suggested by several subsurface faults which appear on some of Park's maps but either do not appear on the references he cited or extend beyond the area covered by such references.

Hall and others (1981) excavated three trenches across the Pleito thrust in an effort to document its recent history of movement. They logged two of the trenches, both of which exposed datable materials, in detail (see Figures 3A and 3B). Based on the information they gleaned from their investigation, they preliminarily concluded that:

1) Repeated movements have occurred along the Pleito fault during late Quaternary time.

2) The most recent movement on the Pleito occurred between 345 and 475 to 1465 ybp (based on radiocarbon dating).

3) Locally the Pleito fault consists of at least two strands which dip southward at angles averaging 20° to 30°.

4) Characteristically, the net slip per event on the Pleito fault appears to be about 1 meter.

Davis (1983) concurred with Hall and others that the eastern segment of the Pleito fault has been active during the Holocene. West of the west end of Wheeler Ridge, Davis described the fault as a 1 km-wide zone. He also noted that west of San Emigdio Canyon this fault zone is mostly overlapped by late Pleistocene deposits (possibly Riverbank Formation or an equivalent). He also states that the Pleito fault appears to die out as a surface feature west of Santiago Canyon. The locations of the various strands of the Pleito fault mapped by Davis appear to be virtually identical to those of Dibblee (1973a; 1973b; 1973c; 1973d; 1973e). However, because Davis' maps are 1:62,500 or smaller scale and are either planimetric or on a generalized base, minor differences are difficult to detect. For this reason, no attempt has been made to plot the Pleito fault as Davis shows it, but selected data (the localities where his Riverbank (?) Formation overlaps the fault strands) have been plotted on Figures 2C and 2E.

Wheeler Ridge thrust fault

During this investigation, no geologic map was found which depicts the Wheeler Ridge thrust as a surface feature. Hluza (1960) determined that the Wheeler Ridge fault is a bedding plane fault at depth, locally dips 40°, and is responsible for more than 600 meters (2000 feet) of displacement. He determined that, in the Northeast area of Wheeler Ridge oil field, the fault dips 60° south and has offset the base of the Tulare Formation (Pleistocene) by about 11 meters (35 feet). Hluza states (p. 63), "As far as can be determined the fault does not extend to the surface." Hluza also reported that there is some evidence of normal faulting in the plate above the thrust. Park (1960) speculated that a thrust fault evident beneath the Windgap area (Sections 35 and 36, T. 11 N., R. 20 W., Figures 2A and 2B) of Wheeler Ridge oil field might also be the Wheeler Ridge thrust.

Shortly after the Hluza (1960) and Park (1960) papers appeared, O'Neill (1961) prepared a supplemental report for the Department of Water Resources, indicating it was based on confidential data and that these data were not available for publication. The purpose of O'Neill's report was to document the refined location of the Wheeler Ridge fault (see Figures 2B and 2C). Apparently, O'Neill was the first person to actually consider that the Wheeler Ridge fault might be recently active.

Basically, O'Neill's report was similar to Hluza's, except that O'Neill's provided more detail on the nature of the fault at depth. O'Neill determined that the Wheeler Ridge fault changes character as it nears the surface. At a depth of 3700 meters (12,000 feet), about 3.2 km (2 miles) south of the crest of Wheeler Ridge, the Wheeler Ridge fault exists as a nearly horizontal bedding-plane thrust. Directly beneath the crest of the ridge, the dip of the fault is about 40° south. O'Neill indicated that the displacement along the fault appears to vary with depth, with the largest displacment amounting to about 700 meters (2300 feet); he did not indicate what unit was offset by this amount, however. He also concluded that Pleistocene deposits are offset about 11 meters (35 feet) or less in the vicinity of the Northeast area of Wheeler Ridge oil field. Based on subsurface data, O'Neill concluded that the location of the Wheeler Ridge fault should coincide with a "topographic break" near the base of the north flank of Wheeler Ridge. He estimated that the fault was about 30 meters (100 feet) wide at the surface, but he provided no further details on the nature of the "topographic break".

O'Neill concluded that the Wheeler Ridge fault extends eastward to State Highway 99. He indicated that wells drilled in Sections 22, 23, 26, and 27, T. 11 N., R. 20 W., intersected a steeply dipping fault plane which he inferred to be the Wheeler Ridge fault. He also indicated that he lacked sufficient data to determine whether the fault extended westward of the Northeast area of Wheeler Ridge oil field.

O'Neill believed that "structural growth" certainly had occurred in the vicinity of the Wheeler Ridge fault during the Pleistocene and probably had also occurred during the Holocene. He cited the possibility that historic movement might have occurred along the fault at depth, but determined that no wells had been drilled through the fault until after the 1952 earthquake, thereby precluding determination of whether or not such movement had occurred during the 1952 earthquake sequence.

The Wheeler Ridge thrust has also been mapped at depth beneath the Ranch area of Pleito oil field (California Division of Oil and Gas, 1973) and the Southeast area of Wheeler Ridge oil field (Barnes, 1964). Barnes reports evidence that two parallel thrusts, about 200 meters (700 feet) apart, locally exist at depth.

Davis (1983, p. 286) describes the Wheeler Ridge fault as a thrust "which does not seem to be exposed at the surface" even though he identifies subsidiary thrust faults in a quarry on the north flank of Wheeler Ridge (his maps are not sufficiently detailed to permit identification of this site on Figure 2B). Davis states that the Wheeler Ridge thrust extends west possibly as far as Santiago Canyon, and is probably overridden by the Pleito fault in the area of the Pleito Hills. His maps suggest that the fault might conceivably connect with the Pioneer fault (a blind thrust located northwest of Figure 2G) west of Santiago Canyon, but that the data in the intervening area is insufficient to determine whether this is the case.

There is some difference of opinion as to whether or not the White Wolf fault truncates the Wheeler Ridge fault. Dibblee (1961) depicts the White Wolf fault as chopping off the leading edge of the Wheeler Ridge fault. Buwalda and St. Amand (1955, p. 56) suggest that the Wheeler Ridge fault overrides the White Wolf fault. O'Neill (1961) suggests that the two faults splay just north of Wheeler Ridge. Davis (1983) indicates that the two zones seem to merge but are difficult to separate out based on the data available.

Stein and Thatcher (1981) analyzed available surveying data in order to determine whether any tilting of the ground surface has occurred in the vicinity of Wheeler Ridge. They determined that between 1942 and 1947, from 4 to 17 microrads of tilt occurred along State Highway 99 near Wheeler Ridge (the epicentral region of the July 21, 1952 earthquake). Based on geodetic and seismic data, Stein and Thatcher calculated that about 3 m (10 feet) of reverse, left-lateral, co-seismic slip occurred at the epicenter. Their post-earthquake data appears of questionable value in the vicinity of Wheeler Ridge since they have apparently only surveyed along State Highway 99 in the vicinity of the ridge itself, and not to the north or south. Their data indicate that the ridge rose about 120 to 165 mm (4.7 to 6.5 inches) between 1953 and 1965, but did not rise appreciably between 1965 and 1974. It appears that most of this apparent uplift occurred north of the projection of the White Wolf fault. Riley (1970) reports a substantial amount of hydrocompaction occurred along the route of the California Aqueduct during construction. This hydrocompaction, along with subsidence due to groundwater withdrawal immediately north of Wheeler Ridge (see Lofgren, 1963), has rendered surveying of questionable value as a technique for determining whether tectonic stresses are presently accumulating (Stein and Thatcher, 1981).

Los Lobos Fold

McGill (1951) mapped two "anticlines" in late Pleistocene (?) alluvium near San Emigdio Ranch, referring to them as the "Morgan swell" (herein referred to as the Los Lobos fold) and "Little swell". He described these "swells" as being 15 to 30 meters (50 to 100 feet) high and having maximum slopes of 9° north on the northern flank and 2° south on the southern flank. McGill apparently believed the area he studied was tectonically active, but had no firm evidence to support active faulting. Dibblee (1972) and Dibblee and Nilsen (1973) depicted the alluvium to be Holocene in age, and did not depict the young folds mapped by McGill. However, it is possible that neither Dibblee nor Nilsen attempted to map the alluviated area in any detail. None of these investigators reported any evidence of faulting associated with the monocline.

Davis (1983, p. 284) refers to McGill's "Morgan swell" as the Los Lobos fold. He states that upper Pleistocene alluvial fan deposits are folded up to

15° on this fold and implies (p. 307) that this fold is the surface expression of a subsurface thrust fault. Davis (p. 307) also states that "the absence of surface rupture does not indicate the lack of recent activity..." along the subsurface fault beneath the fold. Davis neither describes the relationship between the Los Lobos fold and the nearby faults nor does he depict the fold on his maps. However, based on Figure 2F, it appears this feature lies about 1 mile north of and is generally subparallel to his postulated subsurface trace of the Wheeler Ridge thrust.

San Andreas Fault

As noted above, fault rupture occurred along the San Andreas fault in this area in 1857 (Sieh, 1977). A Special Studies Zones map of this segment of the San Andreas fault was issued in 1974 (California Division of Mines and Geology, 1974a). The source of the faults shown on that SSZ map is an annotated map by Vedder and Wallace (1970; see Figure 4). Since their map was published, Davis (1983) has compiled a slightly different version of the fault-related features along the San Andreas fault in the study area. The features he identified as possibly fault produced are plotted in red on Figure 4.

Other Faults

There are numerous other faults in the area studied, but there is little information to suggest that any of these other faults might be active. None of these other faults are mapped as cutting Quaternary deposits. McGill (1951) cited a closed depression along the Williams fault near Camp Marion (southeast of Brush Mountain and Figure 2E) as suggestive of recent movement. However, Dibblee (1973a), who did not show the Williams fault of McGill, shows what appears to be a northeastern extension of the Williams fault as not cutting Pleistocene deposits. Davis (1983) also did not depict McGill's Williams fault. Based on the pattern of faults mapped by Dibblee (1973a; 1973b; 1973c; 1973d; 1973e), O'Neill (1964), Davis (1983), and others, it appears that several of the faults mapped are thrust faults, and are probably part of the imbricate fans of faults that constitute the Wheeler Ridge and Pleito fault systems.

Buwalda and St. Amand (1955) reported three east-northeast trending "earth ruptures" on Wheeler Ridge resulted from the 1952 Kern County earthquakes. These ruptures were long, straight, and crossed the crest of the hills, unlike landslide features observed elsewhere on the ridge. The main fissure was described as striking S 55° W, dipping 50° NW. Gouge 1.6 mm (1/16 inch) thick was found along this fault plane. Grooves and striations indicated right-lateral-oblique slip. Where vertical displacement could be measured, the northwestern block was usually down 0.3 to 1.2 meters (1 to 4 feet), with extensional cracks 15 to 30 cm (6 to 12 inches) wide. The other two cracks were reported to exhibit little or no evidence of strike-slip displacement although their trends (S 50° W) were close to that of the first crack. Vertical displacements along these two cracks ranged from a few centimeters to 1.2 meters (4 feet), northwest side down. Buwalda and St. Amand concluded that these cracks probably were the surface expression of movement along the White Wolf fault which they believed passes beneath Wheeler Ridge. However, the White Wolf fault may merge with the Wheeler Ridge fault in this area (Davis, 1983). Thus, these fissures may simply be secondary faults overlying a primary thrust.

Based on the work of Bruer and others (1952), Jennings concluded that ground rupture occurred on several faults in the northern part of the Coal Oil Canyon quadrangle. In his initial, rapid evaluation, David L. Wagner (1974) apparently concluded that these fissures were lurch cracks and not active faults. No attempt has been made to re-evaluate these fissures during the current fault evaluation effort.

INTERPRETATION OF AERIAL PHOTOGRAPHS

U.S. Department of Agriculture (1952) aerial photographs were interpreted in order to detect features indicative of recent faulting (see Figures 5A through 5H). An effort was also made to delineate identifiable erosional and depositional surfaces which might be useful in establishing the relative age of the features visible on the photographs or identified by other investigators. These photographs post-date the July 1952 Kern County earthquakes.

Four zones of locally well-defined scarps were evident on the photographs. The most prominent of these scarps occurs along the Pleito thrust near Grapevine (Figure 5A). It appears, based on the photographs, that this escarpment can be traced as a nearly continuous feature for a distance of about 5 km (3 miles). Near its eastern terminous, the scarp is evident crossing what appear to be Holocene alluvial and debris flow deposits along Grapevine Creek. Immediately east of these deposits is a large, recently active landslide which has a well-defined scarp at its toe. This scarp may be a product of fault movement, landslide movement, or both. West of Grapevine, the scarp crosses the Holocene (?) alluvial fan of Tecuya Creek. This scarp continues westward into Section 23, T. 10 N., R. 20 W., where it either is obscured by a large landslide or continues along the toe of the slide mass. That the latter occurs is suggested by the presence of a northeastward-facing scarp across the fan of Salt Creek. This scarp across the Salt Creek fan is geomorphically similar to the scarp across the Tecuya Creek fan.

To the north of Salt Creek, Dibblee (1973b) depicts the Pleito fault as concealed along the front of a massive landslide. This landslide toe could well mark the location of an active fault, based on the escarpment present. However, whether this escarpment owes its definition to recent landslide movement, recent fault movement, or both, could not be determined from the photographs. The evidence is permissive of recent faulting.

Northwestward of Section 32, T. 11 N., R. 20 W. (Figure 5D), the Pleito fault appears obscured by a complex of landslides. Nowhere west of these landslides were any well-defined, clearly fault-produced, escarpments, similar to those noted between Salt Creek and Grapevine Creek, evident in young (Holocene or latest Pleistocene) deposits (Figures 5C, 5D, 5E, and 5H). However, escarpments in bedrock, and some possible terrace surfaces, as well as the pattern nearby of landslide failures, suggest that active faults may be present. Time did not permit a detailed analysis of these features, only some of which are shown.

A second zone of well-defined scarps was noted along the north flank of Wheeler Ridge (Figures 5B and 5C). In Section 22, T. 11 N., R. 20 W., one of these scarps is particularly well defined across a fairly recent (probably Holocene or possibly latest Pleistocene) alluvial fan. This scarp, which appears to be at least 2 to 4 meters high, occurs approximately 60 to 120 meters (200 to 400 feet) valleyward of the base of the steeply sloping hillside that forms the north flank of Wheeler Ridge. This is the location of the Northeast area of Wheeler Ridge oil field, where Hluza (1960) and O'Neill (1961) both reported that Pleistocene sediments were offset (in the subsurface) about 11 meters (35 feet) by the Wheeler Ridge thrust and O'Neill referred to a "topographic break" (which was not further described). On the photographs interpreted, other scarps were evident to the southeast, approximately on trend with the scarp across the alluvial fans. As discussed below, a thrust fault was observed in the field approximately coinciding with a scarp in the SE/4 of Section 25, T. 11 N., R. 20 W.

Further to the west (Figures 5F, 5G, and 5H), approximately on trend with the Wheeler Ridge thrust, broad, generally east-west trending "warps" were evident on surfaces interpreted as probably late Pleistocene alluvial terraces (McGill, 1951, concurs). These warps appear to be the surface expression of a monoclinal fold (herein referred to as the Los Lobos fold). It further appears that these surface features locally have been obliterated by San Emigdio Creek and Los Lobos Creek. Low scarps on the surface of the fold, as well as the fold itself, suggest that an active (Holocene) fault probably exists at very shallow depth. Branches of this fault may, in fact, reach the surface, or the scarps may result from movement along secondary faults superimposed on the fold.

The fourth zone of reasonably well-defined, fault-produced topographic features occurs along the north flank of the Pleito Hills between the vicinity of Muddy Creek (Figure 5E) and Pleito Creek (Figure 5F) along the probable extension of the Wheeler Ridge thrust as mapped by Davis (1983; see Figures 2E and 2F). The location of the principal thrust fault zone is inferred based on the steep northern margin of the hills as well as scarps which are locally well defined. In Section 36, immediately east of San Emigdio Ranch, a well-defined scarp exists in alluvium of probable Holocene age. This scarp could be the product of landslide processes, but the existence of similar scarps in older rocks nearby and on trend with the scarp in alluvium suggests it might as easily be the product of recent fault movement. Well-defined, back-facing scarps and benches are locally present within a few hundred to a few thousand feet south of the main fault zone. Although these back-facing features are in bedrock, some are quite sharp and most likely result from bedding-plane slip in the upper thrust plate during Holocene time.

As noted above, Buwalda and St. Amand (1955) reported that fault rupture probably occurred on Wheeler Ridge (Figures 2B and 2C). Of the three northeast-trending faults they depicted on their map, one was delineated as a fairly long, continuous fault rupture. This "fault" could only be verified locally on the aerial photos, in an area which could be the head of a large landslide (Section 27, T. 11 N., R. 20 W.). Here, the "fault" appears as a northeast-trending, northwest-facing scarp with coinciding tonal lineament (presumably the shadow of the scarp and open fissure). This scarp appears slightly sinuous, and is somewhat segmented. This feature can be traced southwesterly across the "stable" ridges. I suspect that this ridgetop feature probably reflects incipient landsliding, but faulting along a bedding plane or hingeline or normal faulting above a primary thrust fault cannot be ruled out as a possible explanation.

Well-defined scarps were also noted to the northwest of this "fault". The latter scarps are generally short, northeast-trending and northwest-facing, and probably result from landslide movement. These short scarps are generally similar to the scarps along the "fault" described in the earlier paragraph, except they mostly could not be traced across any ridgetop areas. A southeast-facing scarp or sidehill bench was apparent across a northwest-facing landslide scarp in Section 28. The cause of this feature could not be determined from the photographs.

U.S. Geological Survey (1966) aerial photographs of the San Andreas fault were briefly reviewed (see Figure 5I). The main trace of the San Andreas appears to be reasonably well defined in this general area. However, a large landslide in the southeastern corner of the Eagle Rest Peak quadrangle may obscure some additional traces of the San Andreas fault. The upslope-facing scarp and bench identified by Davis (1983) in the SE/4 of Section 9 (Figure 4) appears to be confined to this landslide mass. Therefore, it is probably a landslide feature and not a fault-produced feature.

FIELD OBSERVATIONS

Field observations in the area studied were limited. Permission to examine localities on San Emigdio Ranch (which "contains" most of the surface trace of the Pleito fault, the Los Lobos fold, and the western segment of the Wheeler Ridge thrust) could not be obtained except in areas where oilfield roads provided ready access. Thus, segments of these faults could not be field checked. No attempt was made to field check the San Andreas fault in the area studied. A total of 3 days was spent in the field checking other localities.

The only site along the well-defined portion of the Pleito fault that could be examined during this study was immediately north of Grapevine (south of the commercial area on Interstate Highway 5; Figure 5A). Here a well-defined, 7 meter-high (22 foot-high), north-facing scarp is apparent across the older alluvial deposits of Grapevine Creek. The slope of the face of this scarp ranges from 18° to 23°. Part of the scarp visible on the aerial photographs has been obliterated during the construction of Interstate Highway 5. The younger alluvial deposits to the east of the highway lack any well-defined scarp. No faults were observed in any of the walls of the drainage channels in this area.

If the entire 7 meter height of the scarp at Grapevine results from fault movement during Holocene time (which appears reasonable), then the height of the scarp has been increasing at a rate of 0.7 mm/year. If the dip of the fault near the surface averages 20° to 30° (as observed nearby by Hall and others, 1981), then the rate of dip-slip displacement has been about 1.4 to 2.0 mm/year.

On the north flank of Wheeler Ridge, an attempt was made to verify the presence of the well-defined scarp in Section 22, T. 11 N., R. 20 W., earlier described (Figures 5B and 5C). Unfortunately, this escarpment has apparently been destroyed as the result of oil field development and/or the construction of the California Aqueduct. Drainages in the area have partially been filled artificially. As a result, only the portions of the drainages structurally above the postulated thrust could be checked. No faults were observed in the walls of these drainages. Based on the height of the scarp estimated from the aerial photographs (2 to 4 meters or more), the rate of slip on this fault could be as high as 0.5 to 1.0 mm/year.

To the southeast (Section 25), however, exposed in a quarry wall, a reverse fault was observed (Figure 5B). Due to the highly modified topography in the quarry, this site could only be approximately located. It is possible that this fault may coincide with a scarp observed on the aerial photographs, but this is not certain. The fault observed strikes N 78° W, and dips 60° N. Based on the apparent offset of the well-bedded Quaternary sediments, an estimated 3 meters (10 feet) of displacement has occurred along this fault. All of the diagnostic surficial materials have been stripped off of the surface, precluding the determination of whether or not this fault has been active during Holocene time. In the opposing wall of the same quarry pit, no fault was obvious; however, the beds exhibited evidence of a broad fold on trend with the fault.

If it is assumed that the entire 3 meters of displacement occurred during the Holocene, then the rate of slip on this fault would be about 0.3 mm/year. If the older soil unit is older (perhaps Sangamon), the rate of slip would be about 0.046 mm/year.

Still further to the southeast (southern boundary of Section 25), in another quarry wall, a thrust fault was evident (see Figures 5A and 5B). Because of the extensively modified nature of the landscape in this area, this site could only be approximately located. This thrust fault is actually a zone of faults, 0.7 to 1.3 meters wide, which strikes approximately N 75° W and dips about 28° S. Correlation of the sands and gravelly sands on either side of this fault was not possible. The vertical to over-hanging wall of the quarry was 10 to 13 meters high. Using binoculars, it was apparent that the surficial soils were affected by the faulting. A reddish soil (perhaps Sangamon or younger in age but actually indeterminate since no detailed soil surveys of the area are currently available), about 2 meters (5 feet) thick, was clearly present on the downthrown block, but absent on the upthrown block. A lineation was visible in the modern (black) soil to within about 20 centimeters (8 inches) of the ground surface, suggesting recent movement had occurred along the fault. No clear geomorphic features suggestive of recent faulting were observed adjacent to this cut, however, the surface of the ground may well have been graded in this area, and the surface is gentle enough that the site may have been plowed repeatedly in the past.

Two other faults were also exposed in this same quarry wall. One partially exposed fault approximately parallels the fault described in the previous paragraph (Figure 6). About 10 meters of apparently unfaulted sands and gravelly sands separates these two faults. The updip (nearsurface) portion of the partially exposed fault has not yet been exposed by the quarrying activities. The remaining fault appears to be a relatively minor conjugate shear, and was only apparent where it crossed a relatively competent sand horizon. Above and below this sand bed, the conjugate fault could not be traced through the sandy gravel deposits using the tools available at the time.

Attempts were made to detect the active traces of faults along the roads leading to Pleito oil field (Figures 5C and 5D). No obvious fault scarps or faulted deposits could be distinguished in this landslide-prone terrain. Similarly, attempts were made to detect faults in the area north of the Los Lobos fold (Figure 5G; the monocline itself is on San Emigdio Ranch to which, as noted earlier, access could not be obtained). No well-defined scarps or similar features were evident. Limited exposures suggested that the older alluvial deposits might be broadly warped locally, but evidence of faulting was not apparent in the areas checked.

SEISMICITY

On July 21, 1952, a series of earthquakes struck the Kern County area. Fault rupture along the White Wolf fault and several unnamed faults east of Bakersfield accompanied this series of earthquakes. As noted earlier in this FER, fissures were noted across Wheeler Ridge (Buwalda and St. Amand, 1955). Richter (1955) reported that the epicenter of the largest shock in this sequence ($M = 7.7$) was at latitude 35° N., longitude 119° W., which is directly under Wheeler Ridge. Richter also reported that the depth of the shock appeared to be about 16 km (10 miles), although he implies that this depth was probably assumed rather than precisely determined. Several large aftershocks occurred in the vicinity of the main shock, although most aftershocks were determined as having originated to the northeast.

Real and others (1974) do not list any earthquakes larger than M 5.0 in the vicinity of the thrust faults evaluated herein. Summaries of epicenters in Southern California show that only two or three earthquakes, all smaller than 3.0 M, occurred in the study area between April 1 and September 30, 1981 (Allen, 1981). However, during the period from October 1, 1981, to March 31, 1982, innumerable small earthquakes occurred. Many of these epicenters appear clustered in the vicinity of the Los Lobos fold (Allen, 1982). Included in this series were two sizable earthquakes both of which occurred on November 10, 1981 (M_L=4.6, epicenter 35.02 N., 119.13 W., depth 3 km; M_L=4.2, epicenter 35.02 N., 119.18 W., depth 9 km) as well as four aftershocks greater than or equal to M_L 3.0 (Stover and others, 1982; 1983). This seismic activity apparently tapered off by mid-1982, although a few small earthquakes have been recorded as centered in the vicinity of the study area since that time (Allen, 1983a; 1983b). Based on the four summaries by Allen, it appears that few earthquakes have occurred south of the surface trace of the Pleito fault, and that none of these occurred along or near that segment of the San Andreas fault evaluated. However, numerous small earthquakes occurred in the area immediately valleyward of the Pleito fault during the same period.

CONCLUSIONS

Faults and associated folds in the area studied are part of a complex of south-dipping, imbricate thrusts which rim the southern margin of the San Joaquin Valley. The White Wolf fault, which locally ruptured in 1952, is a northeastern extension of this complex. In the study area, the thrust complex includes two major systems of thrust faults -- the Wheeler Ridge thrust system and the Pleito thrust system. These two systems include the two youngest and most important faults in the complex -- the Wheeler Ridge thrust and the Pleito thrust. Total dip separation across the complex may be as great as 7 km (Davis, 1983).

The relationship between the White Wolf fault and the Wheeler Ridge thrust system is unclear; the faults may merge or the White Wolf fault may be truncated by the Wheeler Ridge thrust in the vicinity of Wheeler Ridge. Historic surface rupture reportedly also occurred on Wheeler Ridge in 1952 (Buwalda and St. Amand, 1955). This reported fault rupture on Wheeler Ridge is approximately on trend with the main zone of surface fault rupture along the White Wolf fault. However, the former is separated from the latter by approximately 19 km (12 miles) of Quaternary alluvium within which no well-defined, continuous zone of fault features is apparent. During this fault evaluation it was not possible to confirm or deny whether fault rupture did, in fact, occur on Wheeler Ridge -- the aerial photographs interpreted suggest that at least some of the reported fissures may have resulted from large-scale incipient landsliding rather than tectonically caused fault displacement but that some fault displacement may also have occurred.

At least two zones of south-dipping, recently active thrust faults were verified in the area studied during this investigation. The most obvious of these two zones, the Pleito fault, has been documented as offsetting Holocene deposits near its eastern end (Hall and others, 1981), and thus is clearly sufficiently active. Well-defined fault scarps across the young fans of Grapevine Creek, Tecuya Creek, and Salt Creek (Figure 5A) also suggest that the fault has been active during Holocene or latest Pleistocene time and is well defined in these areas. East of Grapevine Creek, however, a large landslide may override the Pleito fault or the fault may coincide with the location of the landslide toe. Similarly, northwest of Salt Creek, the most obvious geomorphic features suggestive of recent faulting appear to coincide with the toe of a large landslide mass. Whether this high escarpment actually resulted solely from landsliding or from a combination of landsliding and fault movement is not clear. This escarpment can rather easily be traced northwestward from Salt Creek for about 6 km (4 miles). In Section 32, T.11 N., R. 20 W. (Figure 5D), the escarpment is terminated by a large, clearly recently active, landslide mass. Northwestward of this point, the Pleito fault is not known to be a well-defined, recently active fault. However, locally, geomorphic features suggest that one or more possibly active fault traces may exist (Figures 5E).

Hall and others (1981) also concluded that movement has occurred repeatedly on the Pleito fault during late Quaternary time. Based on the height of the scarp at Grapevine, the rate of dip-slip displacement could be as high as about 1.4 to 2.0 mm/year (Smith, this FER).

The second zone of recently active thrust faults occurs along the north flank of Wheeler Ridge (Figures 5B and 5C). The presence of a Quaternary thrust or reverse fault is suggested by subsurface data (Hluza, 1960). During this investigation, additional lines of evidence were developed that suggest this fault not only exists, but has been active during fairly recent time at a fairly high rate (perhaps as much as 0.5 to 1.0 mm/yr, based on the height of the well-defined scarps which were once locally present across some of the alluvial fans flanking the ridge). This fault was locally well defined, and is zonable, even though the scarp no longer exists. The steepness of the northern flank of Wheeler Ridge, coupled with the presence of a few scarps across alluvial fans at the base of this front, is highly suggestive that a recently active thrust fault is present all along the base of this hill-front. It would appear appropriate to infer that such a fault is present, at least in the area between the well-defined scarps visible on the photographs.

To the west, along the northern margin of the Pleito Hills, several reasonably well-defined scarps appear along the probable westward extension of the Wheeler Ridge thrust (Figures 5E and 5F). The steepness of the margin of the hills, the presence of scarps across Holocene alluvium and young (Holocene or latest Pleistocene) landslide deposits, and the presence of apparently fresh-looking, back-facing scarps immediately south of the main scarp suggest that a major, Holocene-active thrust fault exists locally along the hill front. However, between San Emigdio Creek and Los Lobos Creek there exists a north-sloping surface, which might be an old alluvial deposit (Qoa?), that lacks any well-defined scarp, although a broad escarpment does exist in this location. This apparent anomalous situation suggests that either the fault is not active, does not surface in this location, or has somehow been obscured by geomorphic processes. The latter is doubtful, and the features located to the east and west suggest the first possibility is also doubtful. However, the remaining possibility -- that the fault does not reach the surface in this location -- is a distinct possibility especially given the presence of the Los Lobos fold about 2 km to the north.

The Los Lobos fold is a reasonably well-defined geomorphic feature in an area of recent seismicity. The work of McGill (1951) suggests that the late (?) Quaternary alluvium in the vicinity of this monocline has been affected by folding. It is quite possible that thrusting and/or minor secondary faulting has occurred during this folding, and/or that such faulting will occur on the monocline in the future. Previous workers have not documented any well-defined, recently active faults as surfacing on or near this monoclinal warp. Davis

(1983) states that no such faults exist. However, the photos interpreted suggest that minor faults on the fold may be present locally. Permission to check this hypothesis in the field could not be obtained during this investigation. These apparent scarps appear to be well defined. Given the youthfulness of the fold and the sharpness of the scarps, these probable surface faults appear zonable. The recent seismicity in the vicinity of the fold supports this recommendation. In addition, the Los Lobos fold appears ideally located opposite the apparent "gap" in the western segment of the apparently active Wheeler Ridge fault. Therefore, it appears likely that the Los Lobos fold and the Wheeler Ridge thrust may be interconnected in the subsurface in some complex and poorly understood manner.

As indicated above, time did not permit this investigator to complete the evaluation of that segment of the San Andreas fault within the Eagle Rest Peak quadrangle. Based on the mapping by Vedder and Wallace (1970) and Davis (1983), the fault is well defined within the study area. It is likely that the fault trace shown on the existing SSZ map is the main trace of the San Andreas, and that this trace ruptured in 1857. Therefore, I recommend that serious consideration be given to labeling this trace by placing "1857?" on the map. Based on a review of the U.S. Geological Survey (1966) aerial photographs, the additional hypothesized fault trace mapped by Davis (1983) appears to be confined to a large landslide and is off the trend of the main trace of the San Andreas fault. Therefore, it appears the geomorphic features Davis identified are the product of landslide movement.

RECOMMENDATIONS

Based on the information summarized above, revision of the Grapevine, Mettler, Coal Oil Canyon, and Eagle Rest Peak Special Studies Zones (SSZ) maps is recommended. Also, SSZ maps should be prepared and issued for the Connor SW and Pleito Hills quadrangles. Specifically:

(1) The existing SSZ along the Pleito fault should be modified slightly and extended northwestward to include the scarps across the fans of Tecuya and Salt Creeks, and into the Pleito Hills quadrangle (Figures 7A and 7D). This zone should be based on the work of Hall and others (1981), Dibblee (1973b; 1973d), and this FER.

(2) The Wheeler Ridge thrust should be zoned along the north margin of Wheeler Ridge where recent fault scarps were once evident (Figures 7B and 7C). In the intervening areas, the inferred fault should be zoned to provide continuity. This zone should be based on this FER.

(3) The existing SSZ's along the reported 1952 ruptures on Wheeler Ridge should be narrowed somewhat, to be consistent with zoning elsewhere in the state (Figures 7B and 7C). These zones should be based on Buwalda and St. Amand (1955).

(4) The probable fault scarps apparent on the Los Lobos fold should be

zoned (Figure 7E and 7F). Although it is possible that these scarps may not be surface-fault features, they are undoubtedly Holocene in age and reflect the presence of an active fault at very shallow depth. Thus, tectonic folding has occurred and is probably still occurring in the area, especially along the Los Lobos fold. Such folding can impact critical structures and may be accompanied by sizable earthquakes and surface-fault rupture. This zone should be based on this FER.

(5) The scarps and similar fault-produced features along the north margin of the Pleito Hills between Muddy Creek (Figure 7E) and Pleito Creek (Figure 7F) should be zoned. This zone should be based on this FER.

(6) The existing SSZ along the San Andreas fault should not be modified (Figure 7F). The existing zone is based entirely on Vedder and Wallace (1970).

(7) No other faults in the area studied should be zoned at this time.

These recommended revisions are indicated on Figures 7A, 7B, 7C, 7E, and 7F.

Finally, further work appears warranted in this area. To date, most of the geologic studies that have been completed in the Pleito Hills have been oriented towards finding petroleum. The geologic complexities common in areas of thrust fault systems coupled with the difficulties common in trying to identify the precise location of active thrust faults in rugged terrain can very easily result in such faults not being identified. This is especially true if the investigators are not specifically looking for evidence of recent fault movement or are not well versed in the techniques used to identify such faults. Time and access problems made it impossible to fully evaluate the upland areas south of the principal faults identified in this study. Also, there are geomorphic features along or near the western end of the Pleito thrust as mapped by Dibblee (1973a) which suggest that the western end of the fault may not be as inactive as other workers (i.e., Davis, 1983) have concluded.

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I have reviewed this FER and concur with the recommendations, with the recognition that the recent tectonic features of this area are not fully understood.

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March 23, 1984

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FER-150. Figure 1. Location of the Faults and related features evaluated in this FER. Base map modified after Jennings (1975). The area studied is confined within the eight (8) quadrangles indicated below. These letter designations are also used in Figures 2 and 5 (which consist of 6-8 sheets each; e.g., Figures 2A and 5A cover the Grapevine quadrangle).

A = Grapevine 7.5' quadrangle
B = Mettler 7.5' quadrangle
C = Coal Oil Canyon 7.5' quadrangle
D = Pleito Hills 7.5' quadrangle
E = Eagle Rest Peak 7.5' quadrangle
F = Connor SW 7.5' quadrangle
G = Pentland 7.5' quadrangle
H = Santaigo Peak 7.5' quadrangle

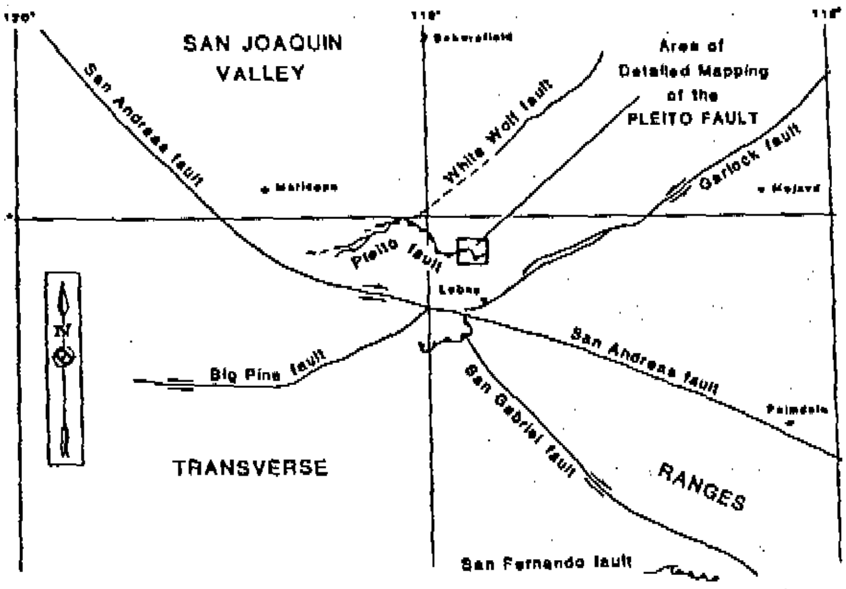


FIGURE 1 - Map of major faults in California
(Modified from Jennings, 1975)

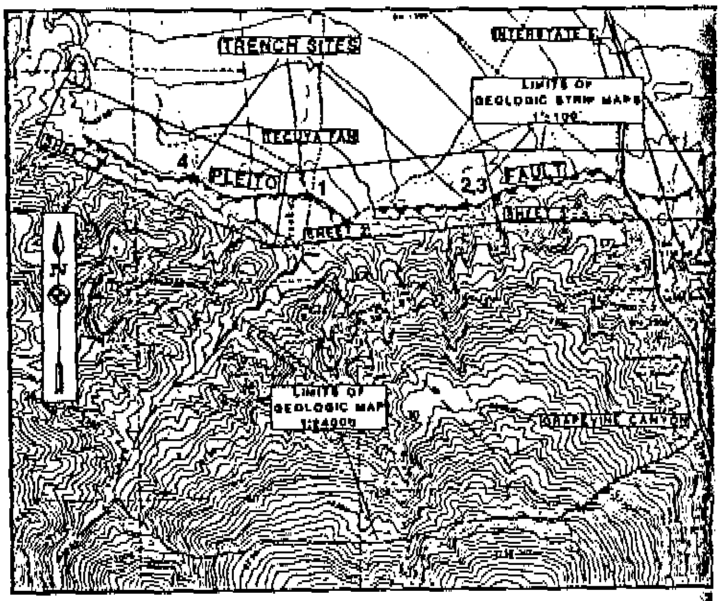


FIGURE 2 - Index Map showing trench sites on Pleito fault and limits of geologic mapping.
Topographic Base U.S.G.S. Grapevine 7.5 minute Quadrangle.

FER-150. Figure 3. Photocopy of trench logs and location maps from Hall and others (1981).

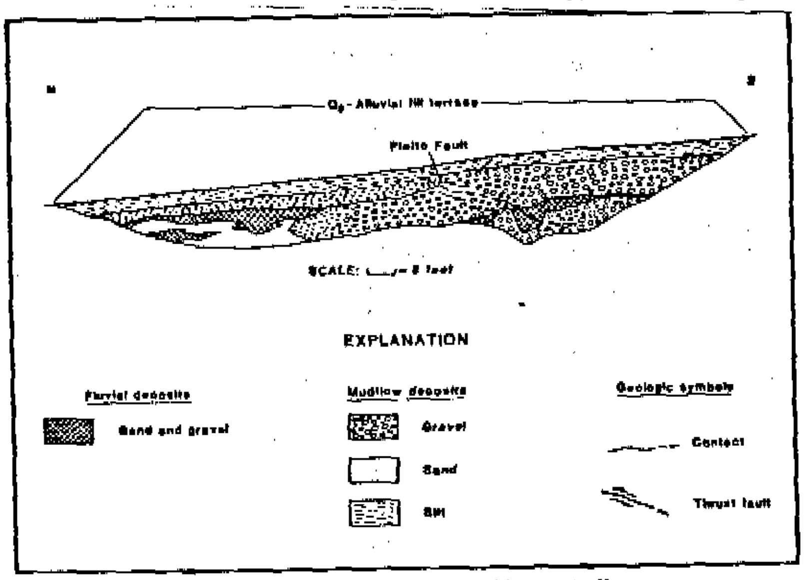


FIGURE 3 - Interpretation of geologic relationships exposed in the east wall of Pleito fault trench "Fumarole 1".

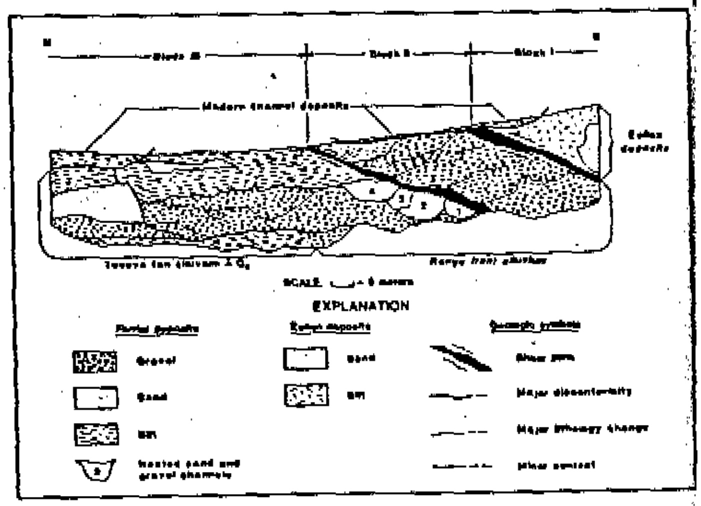


FIGURE 4 - Interpretation of geologic relationships exposed in the east wall of Pleito fault trench "Fumarole 2".

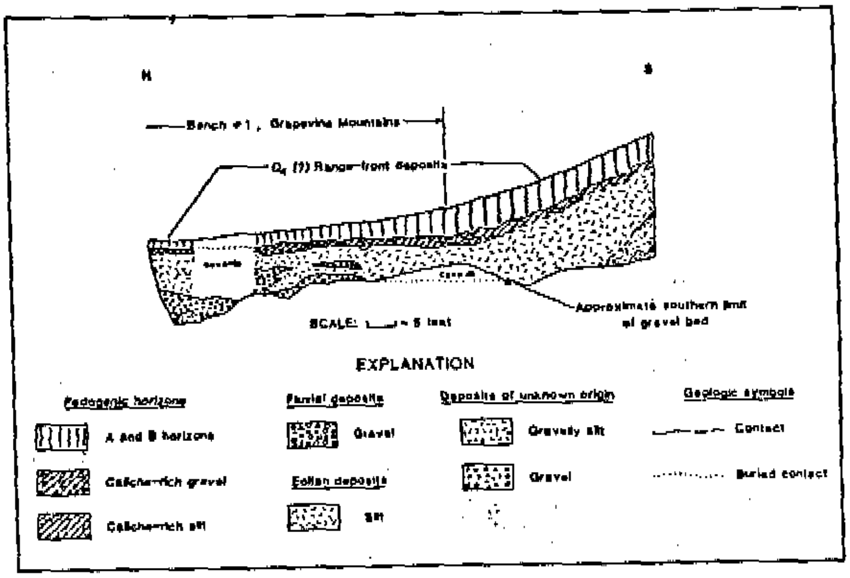
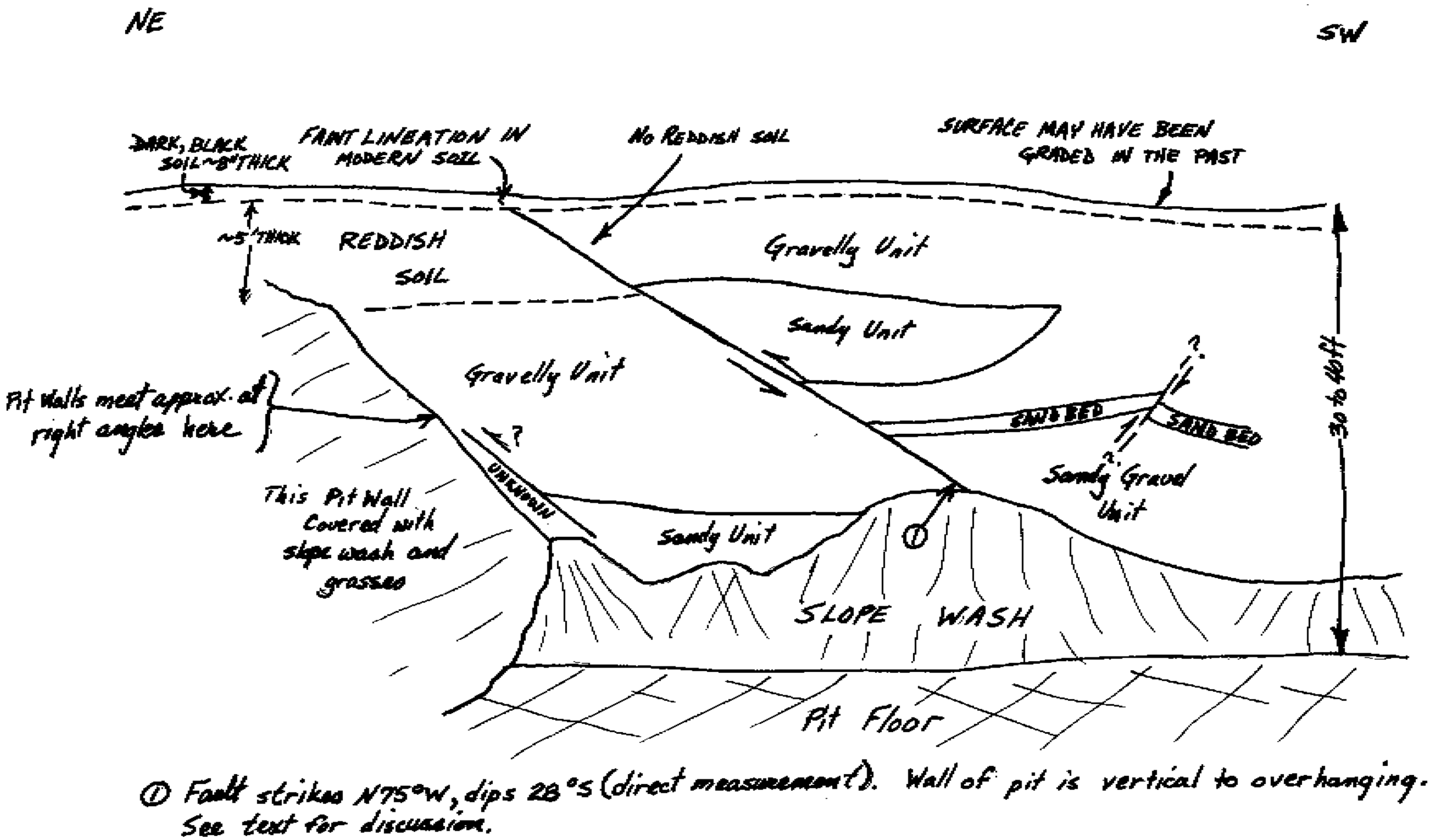
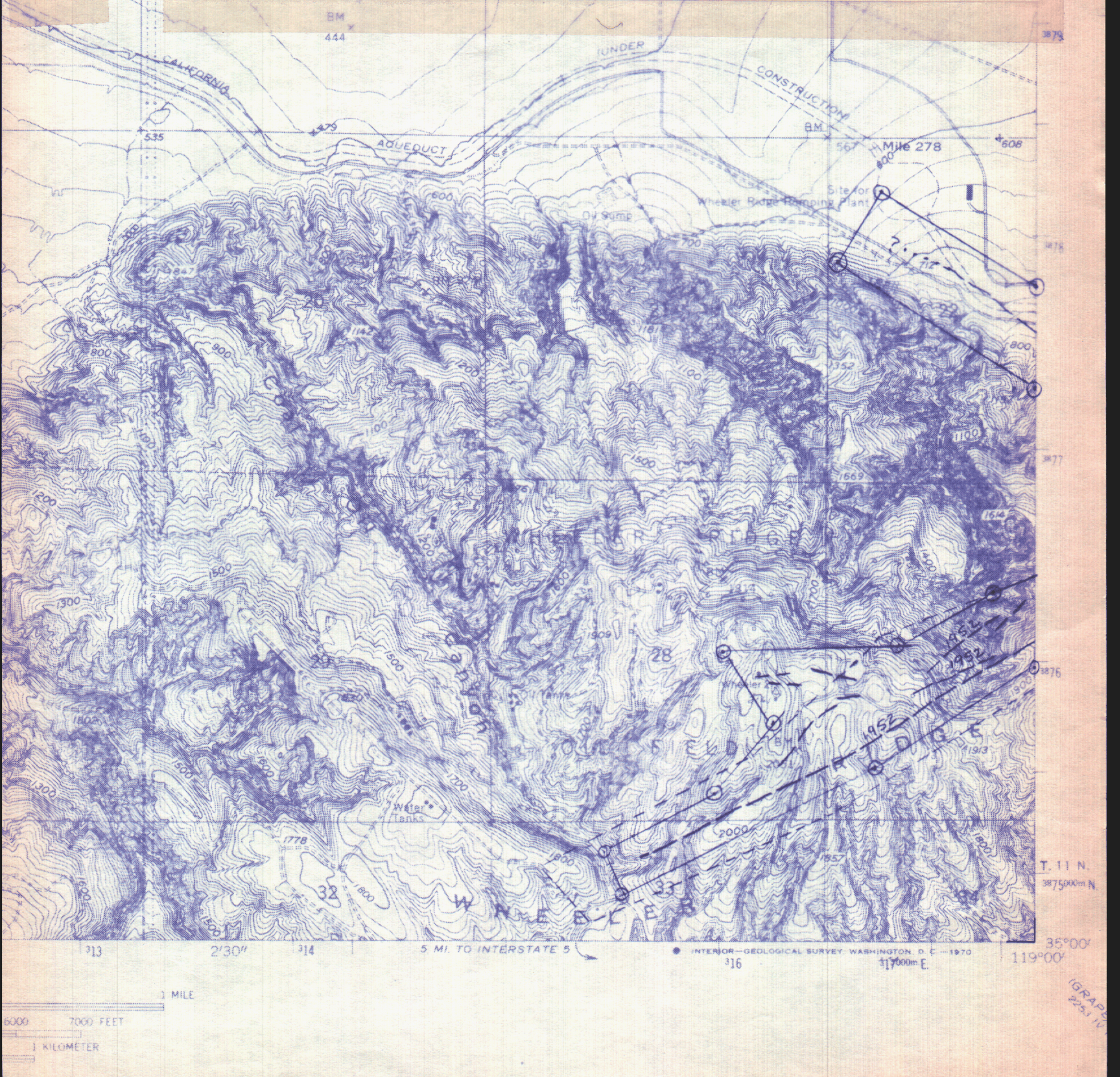


FIGURE 5 - Interpretation of geologic relationships exposed in east wall of Pleito fault trench "Fumarole 3".

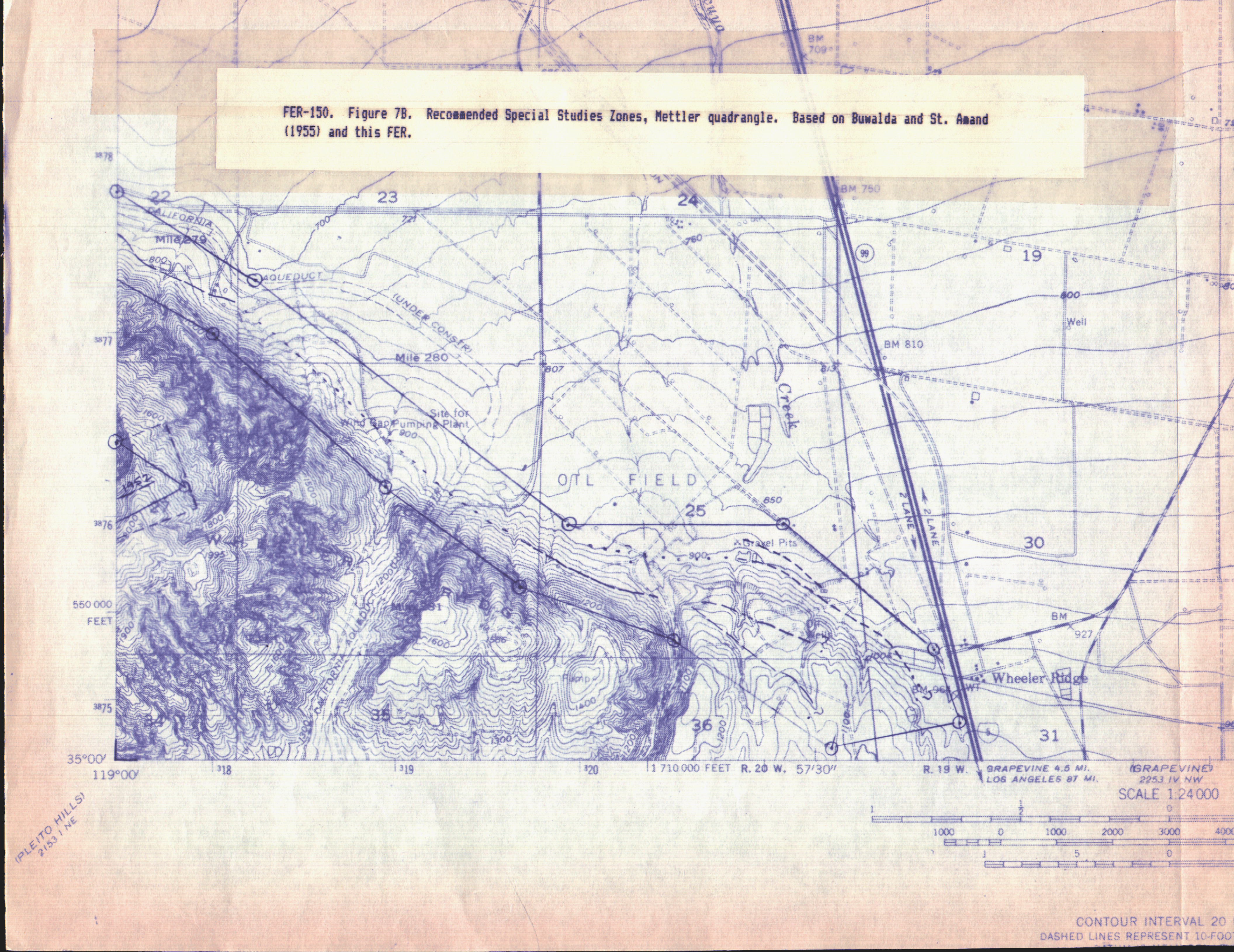


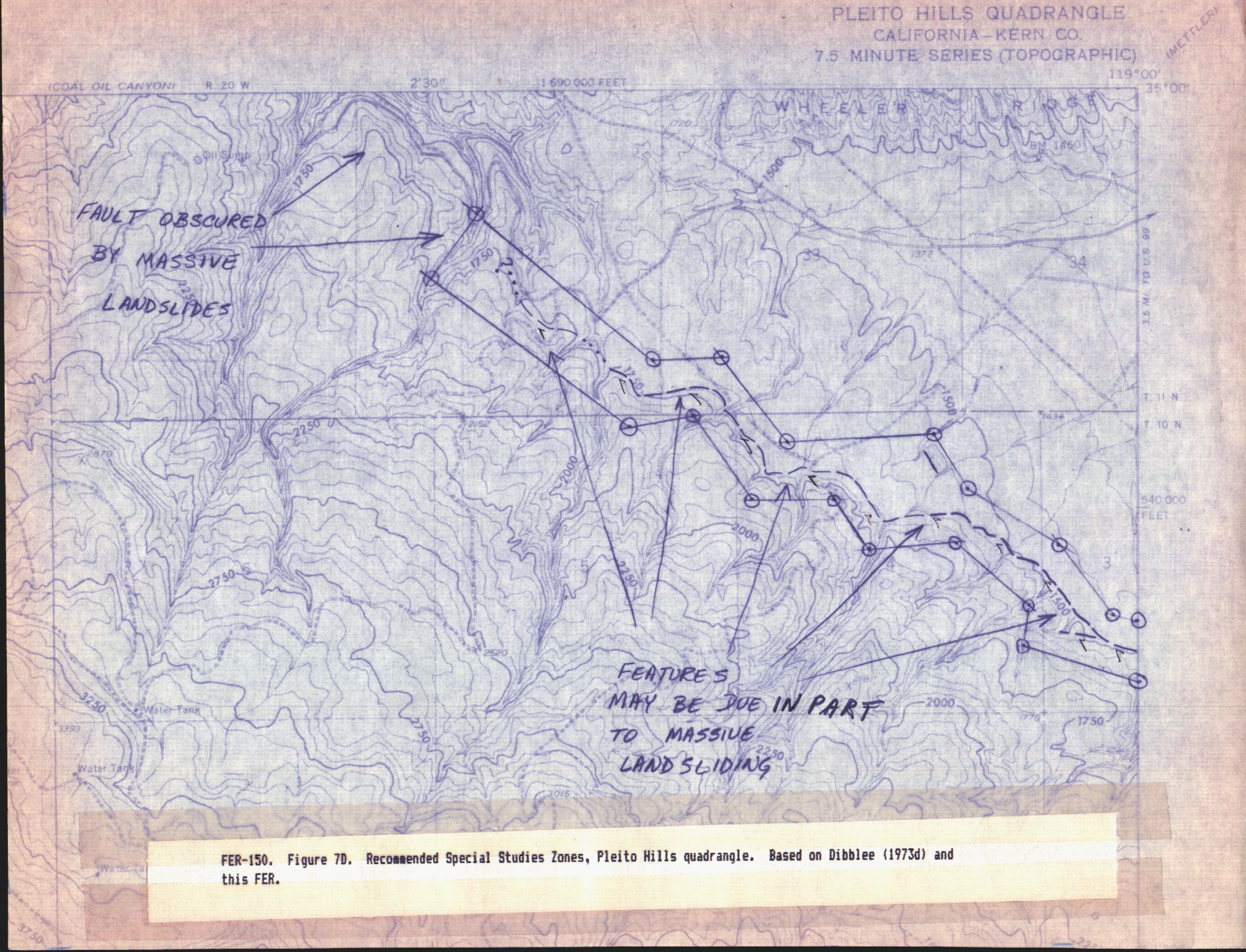
FER-150. Figure 6. Log of quarry face showing thrust and conjugate faults. Log is not to scale. Approximate location is indicated on Figure 5B, on Wheeler Ridge east of U.S. 99 and Interstate 5.

FER-150. Figure 7C. Recommended Special Studies Zones, Coal Oil Canyon quadrangle. Based on Buwalda and St. Amand (1955) and this FER.



FER-150. Figure 7B. Recommended Special Studies Zones, Mettler quadrangle. Based on Buwalda and St. Amand (1955) and this FER.





FER-150. Figure 7D. Recommended Special Studies Zones, Pleito Hills quadrangle. Based on Dibblee (1973d) and this FER.